SCIENCE

FRIDAY, JANUARY 25, 1918

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MSS. intended for publication and books, etc., intended for review should be sent to The Editor of Science, Garrison-on-Hudson, N. Y.

SOME NEEDS OF ENGINEERING[1]

LET me remind you that the practise of our art is still empirical in that most fundamental matter, the strength of the materials which we use, their ability to resist the stresses to which we expose them. It will suffice to touch on two phases of this matter, that our reception tests are quiescent, though in many cases they should be kinetic, and that they do not determine the true resistance of the material even to relatively quiescent stress, as it is applied in many important services. Let us consider these two in series.

It should be an axiom that reception tests should represent the most trying service stresses, which in many important cases are kinetic, arising from impact, shock or very rapid application of stress. This is true of gun hoops, shells, rails, tires, axles, and many parts of motor cars, and of agricultural and other important classes of machinery. The fitness of such materials for enduring these kinetic stresses should be determined primarily by means of impact tests. For each service the severity of this impact should represent the greatest and most rapidly applied stress which is to be expected.

What would you say to using a hydraulic press to determine the ballistic resistance of armor plate or the resistance of a safe to a burglar's sledge? Yet it is only in degree that our present practise is less rational than this, and it is only because fa-

[1] Address of the Vice-president and Chairman of Section G, of the American Association for the Advancement of Science, Pittsburgh, December 28, 1917.

miliarity has dulled our sense of incongruity that we do not rebel against its irrationality.

Machines for determining quantitatively the resistance of steel to impact of any desired degree of violence have been on the market for about twenty years, and they have come into use to a considerable extent in Europe for reception tests, though even there they have not received a fraction of the attention which they deserve, so fully has habit blinded us to the irrationality of our present practise. These machines measure quantitatively the energy consumed in breaking a test piece under impact of given violence, and also the capacity of the material for plastic deformation under these same conditions.

It is pure empiricism to measure fitness for these kinetic conditions by applying a factor of safety to the results of quiescent tests. Not only must such a factor be a matter of guesswork, but that which suffices for certain materials is wholly insufficient for others. We know that certain steels, which we call "fragile," behave well under quiescent tests, but are very brittle under impact. A factor suitable for them would involve a great waste if applied to infragile steel, while one suited to infragile steel might lead to death and disaster if applied to that which is fragile. Unfortunately the fragile and infragile can not be distinguished by our present quiescent tests, though certain causes of fragility can be detected with the microscope. Under these conditions, unhesitatingly preferring waste to disaster, we adopt a factor suited for fragile steels. This in turn means that we load the community with the cost of a superfluity of material in that large majority of cases in which we use infragile steel, lest we invite certain disaster by our present neglect to take the simple precautions of using the impact test so as to detect fragility. To secure infragility by regulating the composition of the product and the process of manufacture is far better than nothing; but these precautions, which the buyer can enforce with difficulty if at all, should in his interest be supplemented by the direct and positive exclusion of fragile material by means of the impact test.

A like overloading occurs through our trying to provide for the shocks incident to these kinetic services by requiring great plastic deformability, which we currently call "ductility," in the shape of permanent elongation and contraction of area under quiescent tests. This provision at first seems wholly irrational, because these services imply no appreciable plastic deformation, so that we demand properties which will never be utilized. Neither guns, nor rails, nor tires deform plastically in use to an appreciable extent. The excuse is that to increase the ductility, even that determined quiescently, is to increase the power to endure shock. Unfortunately the shock resistance thus implied is far less in fragile steels than in infragile ones, so that in order to secure enough of it for the fragile steels which we may use unwittingly we specify a degree of ductility wholly superfluous in infragile ones. This superfluous ductility is very costly, whether it is got without sacrifice of strength by means of special heat treatment or composition, or, sacrificing unit strength, by using much more of a much weaker steel, following the principle that for given grade of steel, every gain of ductility carries with it a corresponding loss of strength. We could save this needless expense by using the impact test and thus detecting fragility, for then we could lessen the ductility which we exact to that needed for infragile steels.

It is beside the mark that for many uses, including some kinetic ones, more material is needed for rigidity than for strength,

and that here the teachings of the impact test would not lead to economy. That cast iron is strong enough for sash weights, flywheels, and bedplates does not prevent our heat-treating alloy steels for aeroplanes.

Turning to our second subject, my assertion that we do not determine the true resistance of our material even to relatively quiescent stress refers to fatigue strength, the resistance to stresses applied repeatedly. Of the four properties which we habitually determine, the elongation and reduction of area certainly throw little light on fatigue strength, nor can we expect much from the tensile strength, which represents the exaltation of the elastic limit induced by the plastic deformation after the initial elastic limit has been passed. This deformation can not be tolerated in hypo-elastic services, that is in those which demand that each member must retain its initial size and shape, and here the ability of the material to undergo the resultant exaltation of its elastic strength is useless, save as forming a basis for calculating the ductility from an additional point of view, through the elastic ratio, and thus supplementing the elongation and reduction of area as suggestions of impact resistance. How is it then with the fourth of these properties which we determine, the elastic limit?

Before answering this, it is well to refresh our conception that, because the innumerable ferrite and cementite grains of our steel lie with their slip planes inclined in every possible direction, and because the stresses are not distributed exactly evenly throughout the member or test piece, there is some one slip plane in some one grain that is less favorably disposed than any of the others towards the existing stress. That is the weakest spot in the bar. If we increase the stress gradually, slip occurs along that slip plane before anywhere else. The failure of this metal to bear its load tends to overload its neighbors. The stress which causes slip along this weakest plane is strictly speaking the true elastic limit, because this slip changes the dimensions of the bar permanently. Perfect elasticity, the power to return exactly to the initial dimensions, exists only below this limit of stress, which hence by definition is the elastic limit. That this first slip can not now be recognized and probably never can be affects this inference as little as our inability to see atoms and molecules interferes with our belief in their existence.

The elastic limit which we determine with our extensometers may, for clearness, be distinguished from the true elastic limit by calling it the "observed elastic limit." That is must needs recede as our extensometers become more sensitive and must thus approach the true elastic limit asymptotically, is clear.

If this stress which has caused the first incipient slip is released, the elasticity of the rest of the metal reverses the slip, and if the stress is quickly reapplied new slip recurs along this same plane, and so on with quickly succeeding applications of stress, according to our conception, which, moreover, holds that this repeated slipping back and forth causes local degeneration. Moreover, the overloading of the adjoining parts by the slip along this one slipping plane leads them in time to begin slipping, so that after many repetitions of the cycle this degeneration extends through so much of the section that the remaining sound metal is unable to sustain the stress, and hence breaks. This leads naturally to the conception that the true elastic limit is the fatigue strength.

Without insisting on the accuracy of this picture, it certainly helps us to understand why our present observed elastic limit does not measure the fatigue strength, and stimulates us to determine much earlier

stages of slip, in the hope that as we approximate the true elastic limit we shall thereby approximate the fatigue strength as well.

Two methods which might lead to much closer approximations than can be expected from refining our direct measurement of the changes of dimension by means of extensometers, are the thermal and the magnetic.

In the thermal method, the fatigue strength is determined as the stress of which rapid repetitions cause a detectable rise of temperature, supposed to represent the heat evolved by the friction along the first slipping planes. This method owes its attractiveness to our conception that the thermo-electric measurements of temperature seem intrinsically capable of greater sensitiveness than the direct measurement of length. On further examination the method loses some of its promise, for though a slip over a very minute area might yield enough heat to be detected if it lay at the very outside of the specimen, if it were deep-seated it might not, because the heat in working outwards would spread itself over a very large area of surface, and this would lessen correspondingly the actual rise of temperature. Hence if we took the stress which causes the first detectable rise of temperature as our best approximation to the fatigue strength, our results might vary greatly with the position of the first slipping area.

The magnetic method would determine the fatigue strength as the least stress of which repeated applications cause a detectable change in the magnetic properties. The developments of this method which are now occurring at the Bureau of Standards deserve our most careful attention.

From the fact that the ability to endure many millions of repetitions of stress is much less than the observed elastic limit, and from our natural explanation that the difference represents some form of progressive degeneration under indefinitely repeated stresses, we naturally infer that when the repetitions are in the hundreds of thousands a like but smaller degree of this same degeneration occurs. From this in turn we infer that even when the repetitions are only in the thousands this degeneration may occur, though in correspondingly smaller amount. From this we generalized that the gap between the observed elastic limit and the safe working load should increase as some function of the number of repetitions of stress to be expected during the life of the member, and we ask whether this increment should not be considered even in designing bridges, and whether it should not increase with their expected life and the frequency of the passage of trains.

A natural question which arises in this connection is whether, as regards fatigue strength, that part of the elastic limit of steel which is caused by a low finishing temperature in rolling is valid or fictitious and removed during the exposure to repeated stresses. The great life of piano wires, strained very severely and exposed to a repetition of stress with each sound wave, and of suspension bridge wires, both of which owe much of their elastic strength to cold deformation in the shape of wire drawing, is reassuring. An interesting case is that of piano wire, which is credibly reported to have sprung back into a helix when cut after fifty-four years' service, showing that it retains even through its enormous number of repetitions of stress the bending given it in coiling it.

Struggling as we are for our national existence, these pale thoughts move us hardly more than the remembrance of his last month's rent stirs the shipwrecked swimmer in his landward struggles.

It is well to ask ourselves frankly how we come to be in this peril to which our minds revert irresistibly. How is it that we and our allies, excelling the Teutons in both the ponderables and the imponderables, in material resources, in wealth, and in population, on one hand, and with immeasurably higher ethical standards on the other, yet can point to no clear evidence of victory? We know that we excel in organizing power. We know that they have no product of organization comparable with our industries of the Ford motor car, the Bell telephone, the Ingersoll dollar watch, the Eastman Kodak, or the United States Steel Corporation. We know that the organization of our transportation is of a higher order of merit than theirs. We know that in these three years the British have made even a better war organization than the forty-four years since Sedan have given Germany. How comes it then that though we are incomparably stronger, richer, and more capable, we are yet in danger of defeat, of national overthrow, of becoming a German satrapy, a second Belgium or Poland? Do we not know that our disadvantage lies in our political system, and that in this struggle for existence it is not showing itself clearly the fittest for survival? Have we not lost sight of this terrible law of the survival of the fittest, not the fittest ethically, or spiritually, or intellectually, but the fittest to destroy competitors physically? What are the ethics of the snake, the tiger, or the hyena that they have survived in this struggle? The bloodthirsty buccaneers were neither the ethical nor the spiritual betters of the Aztecs and Incas. The Romans were the inferiors of the Greeks, yet they overthrew them, and in turn were overthrown by the barbarians. Fitness for survival must be physical.

It is well to ask ourselves frankly whether we have not been living in a fool's paradise. We have rejoiced in the merits of our political system, in the kind of men and women which it has bred, through opening every career to all, through stimulating each one to strive to his utmost in his chosen path. In our natural rejoicing have we not shut our eyes obstinately to its defects? Have we not refused to see that our system necessarily impels those in office to direct their energies towards their own re-election rather than towards the welfare of the state, to please and propitiate the electors rather than to direct and inspire them, to tell them what it is their wish rather than their true interest to hear, and thus in effect to substitute the temporary opinions of the majority, unfamiliar with state matters, for the vision of the born leaders as the determinant of state policy? We rejoice that our system educates the voters in statecraft, that it broadens their horizon, that it breeds strong units, but we have been too weak, too self-complacent to remedy its defects of leaving those units uncemented, so that they form what may be likened to a friable sandstone, a whole which, in spite of being composed of extremely strong units, is yet incoherent.

The state has as a most important duty this strengthening of the individual units, but that does not justify neglecting the equally important duty of perpetuating itself. We make a fetish of our political system and regard its designers as inspired. They certainly were most intelligent and patriotic, and builded well-considering how little actual experimental evidence they had to guide them. But we should not hold their system sacrosanct. Indeed, one essential part of it, the electoral college, soon proved wholly impracticable, impotent to do its work of selecting a president, and became a mere registrar of decisions reached by others. This promi-

nent failure shows what their system really was, an attempt by frail human beings, with very little to guide them, to devise the most difficult of all human institutions, the government of a country. The corruption of our municipal governments is another clear proof of the fallibility of our forefathers, for all these faults result from the environment which they created, and mean that it misfits human nature in these respects.

Naturally erring in the direction of overguarding against the governmental fault from which they were smarting, irresponsibility and consequent tyranny, they devised a government which, as we now see, is so weak as to be terribly helpless, indeed in danger of an impotence which may prevent it from defending itself efficiently against aggressors.

It is this weakness that has put us in our present peril. When Germany began her attempt to conquer the world, her purpose was evident to every broadminded man, and must have been foreseen clearly by many of our political leaders. It was indeed pointed out repeatedly by contributors to the newspapers, and was neither denied nor questioned, but only ignored, with the result, which was clearly inevitable and as clearly predicted, that she has been able to fight her enemies in detail. A government made strong by the fundamental law of the land would have exposed this peril to the voters, and we should not have had for allies an impotent Russia, a crushed Belgium, Servia and Rumania, and a sorely pressed France and Italy. Indeed, it was the known weakness of our system that made the war possible.

A curious contradiction is that the weakness of the government is matched by a tying of the peoples' hands. Not only are we debarred from selecting our rulers and confined to choosing between candidates administered to us by irresponsible organizations, but once we have chosen both we and our representatives are impotent to remedy an error in choice, by compelling a change in administration, as is done with great profit in Britain, France, and elsewhere. Frankly, we should face squarely the fact that our governmental system, as the first of the great experimental democracies, was the work of apprentices, and we should strive earnestly to mend it as soon as we have passed our present frightful peril.

The system and checks and balances, in weakening the people, their representatives, and the administration alike, has put the power taken from them into the hands of irresponsible organizations, the political machines.

I criticize none. The errors of individual officers, from the constable to the President, flow from our system itself. It is the system that needs betterment.

Henry M. Howe

FOOD-BORNE INFECTIONS[1]

Gastro-intestinal disturbance traceable to some food eaten shortly before is a common occurrence and is indeed part of the experience of many persons. Not long since, the majority of such attacks were declared due to "ptomain poisoning" and were deemed to be sufficiently explained by this designation. It was believed, though never, it must be confessed, on very good evidence, that the foods responsible for the trouble had been kept too long or under improper conditions and had undergone bacterial decomposition or spoiling. This decomposition was supposed to have resulted in the formation of ptomains, a

[1] Address of the Vice-president and Chairman of Section K, Physiology and Experimental Medicine, American Association for the Advancement of Science, Pittsburgh, December, 1917.